Parabranchial X-Cell Lesions in Trawl-Caught Pacific Cod *(Gadus macrocephalus)* off the West Coast of Canada--Incidence and Effects

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PARABRANCHIAL X-CELL LESIONS IN TRAWL-CAUGHT PACIFIC COD (*Gadus macrocephalus*) OFF THE WEST COAST OF CANADA-- INCIDENCE AND EFFECTS

by

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ABSTRACT

Westrheim, S. J. 1987. Parabranchial X-cell lesions in trawl-caught Pacific cod (Gadus macrocephalus) off the west coast of Canada--incidence and effects. Can. Tech. Rep. Fish. Aquat. Sci. 1593: 45 p.

The study chronicled the varied nomenclature of parabranchial lesions in Pacific and Atlantic cod (Gadus macrocephalus and G. morhua); investigated lesion incidence with respect to sampling method, length interval, sex, area, season, year, and cod abundance; investigated lesion effects with respect to maturity, growth, and mortality rate; and reviewed results of other investigations.

Parabranchial "growths" were first described in 1929 as adenocarcinomas (W. Pacific) and adenomas (E. Atlantic). The cancerous "tumor" diagnosis was finally abandoned for parasite-caused X-cell lesions in 1981.

During 1968-85, 238,699 trawl-caught cod from off western Canada were examined for lesion incidence. During 1973-85, 47,643 of these were also examined for gonad condition, by sex. Lesion incidence ranged from 0.7 to 18.0%, and varied, not always systematically, with all the above-mentioned factors; inversely with length in all cases; poorly with cod abundance; and directly with sea-lion abundance. Lesion effects included delayed maturity, inhibited growth, and increased mortality rate.

Results of other investigations occasionally differed from those of the current study.

RÉSUMÉ

Westrheim, S. J. 1987. Parabranchial X-cell lesions in trawl-caught Pacific cod (Gadus macrocephalus) off the west coast of Canada--incidence and effects. Can. Tech. Rep. Fish. Aquat. Sci. 1593: 45 p.

La présente étude est une chronique de la nomenclature des lésions parabranchiales chez la morue franche (Gadus morhua) et la morue du Pacifique (Gadus macrocephalus). Elle a aussi porté sur l'incidence de lésions en fonction de la méthode d'échantillonnage, de l'intervalle de longueur, du sexe, de la région, de la saison, de l'année et la l'abondance de la morue. De plus, elle s'est penché sur l'action des lésions sur l'état de maturité, le taux de croissance et le taux de mortalité. Les résultats d'autres études sont aussi examinés.

Les "tumeurs" parabranchiales ont été décrites pour la première fois en 1929 comme des adénocarcinomes (Pacifique ouest) et des adénomes (Atlantique est). En 1981, on a finalement abandonné le diagnostic de "tumeur" cancéreuse en faveur de lésions des cellules X causées par des parasites.

De 1968 à 1985, on a examiné 238 699 morues capturées au chalut dans les eaux hauturières canadiennes du Pacifique afin d'y relever l'incidence de lésions. De 1973 à 1985, 47 643 de ces morues ont aussi fait l'objet d'un examen afin de déterminer la condition des gonades selon le sexe. L'incidence de lésions allait de 0,7 à 18,0 % et variait, pas toujours systématiquement, en fonction des facteurs susmentionnés : inversement avec la longueur dans tous les cas, faiblement en fonction de l'abondance de la morue et directement en fonction de l'abondance de l'otarie. L'action des lésions comprenait un retard de la maturité, une inhibition de la croissance et un taux accru de mortalité.

Les résultats d'autres études étaient parfois différents de ceux obtenus au cours de la présente étude.

INTRODUCTION

Anomalous growths on the parabranchial bodies of Atlantic cod (Gadus morhua) and Pacific cod (G. macrocephalus) were first reported in 1929, as cancerous tumors, simultaneously by Peyron and Thomas (for Atlantic cod), and Takahashi (for Pacific cod)[a]. No further studies seem to have been undertaken until the 1960s. Nomenclature varied as to tumor "types" until 1981, when new, and rather sophisticated, evidence led to the adoption of the "parasite hypothesis", and the currently accepted term X-cell lesions to describe these growths. The first report for Canadian waters was that of Levings (1968)[b], whose findings led to initiation, in April 1968, of a program to monitor the British Columbia trawl landings of cod for incidence of these "tumors". Monitoring has continued uninterrupted to date. Results for 1968-73 were reported by Stich et al. (1976).

This report chronicles the varied nomenclature of parabranchial lesions in Pacific and Atlantic cod; investigates lesion incidence in, and effects on, Pacific cod off western Canada during 1968-85; and reviews results of other investigations there and elsewhere.

HISTORY OF NOMENCLATURE

Nomenclature of cod parabranchial lesions has been diverse: adenocarcinomas (Takahashi 1929); adenomas (Peyron and Thomas 1929); carcinoids (Lange 1973); chemodectoma-like tumors (Lange and Johanneson 1977); tumors (Stich et al. 1976; Wellings et al. 1977; McCain et al. 1978; McCain et al. 1979); "tumors" (Alpers et al. 1977); and X-cell lesions (Dawe 1981; Morrison et al. 1982).

Parabranchial lesions were assumed to be cancerous tumors until two separate teams independently discovered, and jointly reported, that these lesions contained X cells (Alpers et al. 1977). Furthermore, these X cells were morphologically identical to X cells described by Brooks et al. (1969) in skin "papillomas" of pleuronectids in the eastern Pacific Ocean; and by Ito et al. (1976) for pleuronectids and gobiids in the western Pacific Ocean. X cells are unlike any known normal or abnormal cells indigenous to the host species. Brooks et al. (op. cit.) hypothesized that X cells might be exogenous, unicellular organisms, rather than transformed fish cells. Alpers et al. (op. cit.) noted: "The cytologic findings accent the question of whether cutaneous papillomas of pleuronectids, as well as pseudobranch tumors of gadids, are parasitic rather than neoplastic. In view of the current uncertainty, the term "tumor"in this report is used with circumspect (sic) to include xenomas as well as "proper neoplasms" (op cit. p. 377).

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[a]Cited by Wellings (1969).
[b]Incorrectly attributed to Forrester (1969) by Stich et al. (1976).

The discovery of X cells in cod parabranchial bodies further strengthened the possibility that these X cells might be unicellular organisms; and also weakened the possibilities that the pleuronectid and gobiid epidermal lesions were indeed "papillomas", or that X cells were caused by a virus, an alternative hypothesis of Alpers et al. (1977), and Wellings et al. (1977).

Substantive, but not conclusive, evidence supporting the unicellular-organism hypothesis was provided by Dawe (1981), based on three new lines of investigation: (1) imprints, histology, cytochemistry, and electron microscopy; (2) nuclear-flow DNA analysis by flow microfluorometry; and (3) isozyme studies (electrophoresis). He concluded that "X cells are individuals of some protistan species, possibly a member of the family Hartmannellidae" (op. cit. p. 41). Morrison et al. (1982) accepted the new "parasite" hypothesis.

METHODS AND MATERIALS

SAMPLES

Three types of Pacific cod samples were available for analysis--standard dockside (STD), special dockside (SPD), and research vessel (RV). Only the STD samples were collected during the 1968-73 phase, reported by Stich et al. (1976).

Standard Dockside Samples

Each STD sample consists of 120-300 cod collected from the landing of a single trawl vessel whose area of catch is known. Each cod in sample is measured fork length to the nearest centimetre, and tallied on the sample sheet by centimetre interval. If the cod are not dressed (head-on) at sea, the lengths are usually tallied by sex. If the individual fish are examined for parabranchial lesions, a secondary tally of specimens with lesions, by sex and/or length, is recorded on the same sample sheet. The primary purpose of STD samples is to monitor the size and age composition of Pacific cod landed by trawlers. For the current study, STD-sample records for 1968-85 have been utilized, with sexes (if recorded) combined.

Special Dockside Samples

SPD samples are sub-samples (sometimes 100%) of some of the STD samples. Collection began in 1973, and is continuing. For each specimen in sample, the following biological information is recorded: fork length (nearest centimetre), sex, gonad maturity, and (usually) presence of

parabranchial lesions. SPD samples are designed to monitor the gonad development and size at maturity, by sex, of Pacific cod landed by trawlers. Hence, sampling is largely restricted to October-April, with principal emphasis on January-March, the spawning season.

Research Vessel Samples

RV samples were collected from two major cod-trawling areas (3C and 5C+5D) (Fig. 1) during April, July, and October 1975, and February 1976 (Westrheim 1977a). For each specimen collected, the following information, relevant to this study, was collected: fork length (nearest centimetre), sex, gonad maturity, and presence of parabranchial lesions. A stratified sampling scheme was employed in each area-time cell such that no more than 10 cod of each sex were selected whose fork length was the mid-point of each 3-cm length interval (20, 23, etc.), except that all cod longer than 71 cm FL were processed. Principal purpose of the exercise was to determine the length-weight and length-girth relationships, by sex, for Pacific cod in British Columbia waters.

COMPILATION

All samples were compiled into area-time cells defined as major statistical area (Fig. 1) and quarter-year (Jan-Mar, etc.), with two exceptions. First, STD samples from Area 4B were also sub-divided by minor statistical area (MSA) (Fig. 2) and quarter-year, because of the substantial variation in lesion incidence among and within MSAs. Second, RV samples from Areas 5C and 5D were combined, because of small sample sizes.

Length-frequencies were compiled in 3-cm intervals, such that 20 cm = 19+20+21 cm; 23 cm = 22+23+24 cm; etc.

CHI-SQUARE TESTS

Chi-square tests were employed to quantify deviations from expected values, or independence of two or more observations when neither could be categorized as "expected". In the former case, the conventional Chi-square test was employed (Dixon and Massey 1969, p. 238). In the latter case, 2 X N contingency tests were employed, with N-1 degrees of freedom (op. cit., p. 240).

LESION INCIDENCE

Incidence of parabranchial lesions was investigated with respect to sampling method, length interval, sex (where appropriate), area, and cod abundance. STD, SPD and RV samples were utilized, as appropriate.

LESION EFFECTS

Effects of parabranchial lesions were investigated with respect to maturity, growth, and mortality rate.

Maturity

Gonad maturity studies utilized SPD samples collected from Areas 4B, 3C, and 5C+5D during January-March 1973-85, the spawning season. They involved two inquiries: (1) length interval at which 50% of the sample is mature; and (2) lesion incidence, by length-interval, among immature and mature cod.

Growth

Growth of Pacific cod in Areas 5A and 5B, expressed as mean length at ages 2 and 3, was compared with lesion incidence in Pacific cod landed from Areas 5A and 5B during April-June and July-September 1968-84. Mean lengths at age were obtained as a by-product of the Foucher-Fournier (1982) method of deriving age-frequencies from length-frequencies (R. P. Foucher, pers. comm.).

Mortality Rate

Total instantaneous mortality rates (Z) were compared with corresponding, and sharply contrasting, lesion incidences for Pacific cod in Areas 5A and 5B during April-September 1968-84 to determine whether parabranchial lesions were lethal to Pacific cod. The principal cod grounds, Cook Bank (5A) and Goose Island Bank (5B), are only 20-30 nautical miles apart (Fig. 3) (Westrheim and Tagart 1984). Estimates of Z were derived from mean age compositions of cod landed from Areas 5A and 5B during April-September 1968-84. R. P. Foucher (pers. comm.) provided an updated version of the age compositions reported in Foucher and Westrheim (1983). Computation of Z involved the conventional regression of ln N/h on age, for age-classes 3-6. Two estimates of Z were calculated. The first involved the cumulative numbers landed per hour trawled for age-classes 3-6 during April-September 1968-84. The second involved the cumulative age composition (N/h) of year-classes 1966-81, for age-classes 3-6.

GENERAL RESULTS

During 1968-85, 238,699 trawl-caught Pacific cod were examined for incidence of parabranchial lesions--236,355 in STD samples, and 2,344 in RV samples (April 1975-February 1976) (Table 1). A total of 45,299 cod were examined in SPD samples (STD sub-sample).

SPD samples contained 23,257 males and 22,042 females, RV samples contained 1,075 males and 1,269 females.

LESION INCIDENCE

SAMPLE TYPE

Total

Lesion incidence was 3.5% in STD samples; 2.4% in SPD samples; and 8.1% in RV samples (Table 2). Incidence was significantly smaller in the SPD sample than in the STD sample ($X^2 = 157$; $P<.01$), perhaps due to differential seasonal sampling. The evident significantly higher incidence of lesions in the RV samples is presumed to be due to: (1) a smaller "swelling" was adjudged to be a lesion in cod examined aboard the research vessel; and/or (2) smaller lesions might have "shrunk" during storage in ice or refrigerated sea water aboard the trawler, and hence were less detectable at dockside (N. Venables, Senior Port Liaison Officer, pers. comm.).

Length Interval

Among length intervals, lesion incidence exhibited a general inverse relationship to length interval in STD, SPD, and RV samples (Table 2). For sexes combined, STD and SPD sample distributions were unimodal, at 41 cm (6.5 and 5.4%), while the RV sample distribution was multi-modal, at 26 (22.0%), 44 (17.4%), 62 (2.8%), and 77 (1.8%) cm. These modes correspond roughly to mean lengths at ages 1.0 (26 cm), 2.0 (41 and 44 cm), 4.0 (62 cm), and ~6.0 (77 cm). Age-1 cod are not well represented in the dockside samples because few are of marketable size, and hence are discarded at sea, if caught.

By Sex

Lesion incidence in SPD samples was 2.8% among males, and 2.0% among females-- significantly different ($X^2 = 39.3$; $P<.01$) (Table 2). In RV samples, incidence was 7.4% in males, and 8.9% in females--not significantly different ($X^2 = 1.488$; $P>.20$). The large numbers of cod in the SPD sample probably contributed to the "significant" value of Chi-square.

For both sexes, lesion incidence in SPD and RV samples exhibited a general inverse relationship with length interval (Table 2). In SPD samples, the male distribution was essentially uni-modal at 41 cm (6.4%), while the female distribution was tri-modal--38 cm (8.1%), 47 cm (5.1%), and 68 cm (1.1%). In the RV samples, males were similarly uni-modal, at 44 cm (20.9%), while females exhibited four prominent modes--29 cm (14.5%), 38 cm (14.7%), 50 cm (21.1%), 62 cm (4.2%), and 71-74 (1.4%).

AREA

Total

Lesion incidence varied substantially and systematically among areas regardless of sampling method (Table 3). For both STD and SPD samples, maximum incidence occurred in Area 5A (11.0 and 11.8%). Temporal variations in sampling effort among methods preclude any further inter-method comparisons for the January-December data.

Among the STD samples, lesion incidence was substantially higher in Areas 3C (5.4%), 3D (8.4%), and 5A (11.0%) than in 5B (3.0%), 5C (1.5%), 5D (1.9%), and 4B (0.7%). Chi-square tests indicated significant differences in incidence between 3C and 3D ($X^2 = 32.3$; $P<.01$), but not between 5C and 5D ($X^2 = 2.976$; $P>.05$). Obviously, lesion incidences in Areas 4B and 5A differed significantly from those in adjacent areas.

Length interval. In STD samples, modal lengths of cod with lesions were generally smaller than the modal lengths of all cod sampled (Fig. 4). The exceptions were Areas 4B and 5C.

Sexes. Lesion incidence among sexes in SPD samples differed significantly only in Area 3C--5.0% for males and 2.9% for females ($X^2 = 30.3$; $P<.01$). For the remaining areas, incidence ranges were 1.2-13.2% for males, and 1.0-10.6% for females ($X^2 = 0.005$-2.486; $P>.90$-$.10$). In RV samples, lesion incidence among sexes was not significantly different in 3C (17.8% vs 18.3%; $X^2 = 0.010$; $P>.90$) or 5C+5D (1.6% vs 2.0%; $X^2 = 0.138$; $P>.70$).

Seasons. For combined areas, maximum incidence in STD samples occurred during April-June (4.8%) (Table 4). Other values were 3.6% during July-September, 2.9% during October-December, and 2.3% during January-March.

Among-area patterns of incidence values were the same in each quarter-year. All four maximum values occurred in Area 5A (7.3-13.7%), and values for Areas 3C and 3D (2.9-10.0%) were larger than those in 4B (0.4-1.5%) or 5B, 5C, and 5D (1.1-4.2%).

Within-area patterns of incidence values differed among quarter-years, without evident pattern. Numbers sampled generally reflected the magnitude of landings. Area 4B was unique among areas in that, due to

regulations and economics (Westrheim 1977b), Quarters I+IV accounted for 80% of the cod sampled, and 74% of the cod landed, during 1968-85. Elsewhere, Quarters II and III were the principal production periods--56-97% of the cod sampled, and 49-89% of the cod landed.

Years

Among-year trends in lesion incidence in STD samples were roughly similar for all areas except 4B (Fig. 5). The pattern for Area 4B was below-average incidence values during 1969-76, and above-average values during 1977-79 and 1981-85. The pattern for Area 5D was virtually the opposite, and all other areas exhibited below-average values late in the study period. The anomalous results for Area 4B prompted a detailed examination of the STD samples from there.

Area 4B

Within Area 4B there are 11 minor statistical areas (MSAs)--numbers 12-20, 28, and 29 (Fig. 2). MSAs 14, 17, 18, and 19 account for most of the cod landed--85% during 1968-85 (Fig. 6). These four MSAs also accounted for 82% (37,795) of the total cod collected in STD samples from Area 4B. The seasonal nature of landings and numbers sampled for lesions is evident in all important MSAs (Table 5).

Important MSAs. Lesion incidence was maximal in MSA 19, regardless of season, and declined northward to MSA 14 (Table 5). Overall mean incidence was 1.7% in MSA 19, 0.5% in MSA 18, and 0.1% in MSAs 17 and 14. Among quarter-years, a similar pattern was evident.

Years. Prior to 1974, lesion incidence was low (0-0.2%) in all MSAs (Table 6). For MSA 19, incidence was 0.2% in 1970, the only year of sampling prior to 1974, but after 1973, incidence rose rapidly to 3.3% in 1978, and remained relatively high (0.7-2.3%) thereafter. MSAs 17 and 18 exhibited similar patterns through 1979, the last year samples were collected in those MSAs. The rapid increase in lesion incidence coincided with a substantial increase in cod landings from MSA 19, and MSA 18 to a lesser extent (Fig. 6). The "new" fishery in MSA 19 was attributed to an anomalous emigration of Pacific cod from the offshore grounds in Area 3C (Westrheim and Pedersen 1986). The inshore-offshore cline in lesion incidence provides additional circumstantial evidence to support their hypothesis.

COD ABUNDANCE

Pacific cod production fluctuates dramatically in British Columbia waters (Fig. 7). These fluctuations largely reflect the abundance of individual year-classes, which pass through the fishery rather quickly (Westrheim and Foucher 1986). Cod growth is rapid, and life is short.

Marketable size is reached at about age 2, and few cod appear to survive to ages greater than 7. Hence, the attempt to relate lesion incidence to abundance was limited to age-2 and age-3 cod.

Results were disappointing. No definitive relationship was discovered for lesion incidence and cod abundance. The initial investigation involved lesion incidence of "age-2" (actually 46-51 cm FL) cod and LPUE (N/h) of age-2 cod landed during April-June 1968-82, from Area 3C (Big Bank) and Area 5A. A weak inverse relationship was evident in each case--R^2 = 0.13 and 0.08 (Fig. 8). Additional analyses dealing with age-2 and age-3 cod landed during April-September 1968-85 from Areas 5A and 5B produced similar results, as summarized below:

Age	Area	Regression	R^2
2	5A	15.7 -.008X	.003
	5B	6.84-.059X	.10
3	5A	9.01-.020X	.01
	5B	1.71-.165X	.03

Despite these results, the general decline in lesion incidence during 1978-85 (Fig. 5) coincides with coastwide decline in cod landings and abundance reported by Westrheim and Foucher (1986) (Fig. 8).

LESION EFFECTS

Lesion effects gleaned from this study were: inhibited maturation and growth; and increased mortality rate.

MATURITY

Analysis was restricted to SPD samples collected during January-March from Areas 4B, 3C, and 5C+5D. No samples were collected from Areas 3D and 5A, and too few from Area 5B. Data from Areas 5C and 5D were combined, because lesion incidences were not significantly different, as follows:

Sex	Area	% Incidence	N	x^2	P
Male	5C	0.9	1,076	0.110	>.70
	5D	1.1	3,240		
Female	5C	0.7	1,166	0.913	>.30
	5D	1.1	3,182		

RV samples were excluded due to small sample sizes.

Lesion incidence, during January-March 1973-85, was significantly different among sample types in three of the four study areas, as shown below:

Area	Sample	% Incidence	N	X^2	P
4B	STD	1.0	11,514	50.0	<.01
	SPD	2.0	5,041		
3C	STD	3.7	16,947	7.764	<.01
	SPD	3.1	9,054		
5C	STD	1.0	4,777	0.727	>.30
	SPD	0.8	2,202		
5D	STD	1.7	11,917	13.2	<.01
	SPD	1.1	6,422		

Since STD samples contain more specimens in each area, there is legitimate doubt as to how representative are the SPD samples from Areas 4B, 3C, and 5D.

Fork Length at 50% Maturity

Parabranchial lesions inhibited gonad maturation, at least for male cod. Length at which 50% of male cod were mature was larger for cod afflicted with lesions than for those not so afflicted, in Areas 3C (47 vs 44 cm) and 5C+5D (50 vs 47 cm) (Table 7). Inadequate numbers sampled precluded a comparison of males in Area 4B, and for females in all three areas.

Incidence by Maturity

Lesion incidence was 2.3-31.2% in immature cod, and 0.2-3.2% in mature cod (Table 8). In all cases but one (males, 4B), incidence was significantly higher in immature cod, regardless of sex (X^2 = 10.8-811; P<.01). Among immature cod, lesion incidence did not differ significantly among sexes (X^2 = 0.513-3.561; P>.30-.05). Among mature cod, lesion incidence was always significantly higher among males (X^2 = 12.8-89.4; P<.01).

GROWTH

Mean lengths of age-2 and age-3 cod were consistently larger in Area 5B than in Area 5A, during April-June and July-September (Table 9). In the four comparisons, mean lengths were 1.6-3.7 cm (3.2-6.4%) larger.

MORTALITY

Estimates of instantaneous total mortality rate (Z), during April-September 1968-84, were 1.33 (age classes) and 1.47 (year-classes) for cod in Area 5A, compared to 0.98 (age classes) and 1.07 (year classes) for cod in Area 5B (Table 10). Z values were thus 36-37% greater in Area 5A, where lesion incidence was 10.9-11.3%, than in Area 5B, where lesion incidence was 2.3-3.7% (Table 4). However, for this difference to apply to the instantaneous natural mortality rates (M), the instantaneous fishing mortality rates (F) would have to be similar in the two areas--M = Z-F. F values are thought to be similar in Areas 5A and 5B. Cod landings are somewhat larger from Area 5B (Table 4).

COMPARATIVE RESULTS FROM OTHER INVESTIGATIONS

LESION INCIDENCE

Among Regions

Mean incidence was relatively low in the eastern (2.1%) and western (2.0%) Atlantic Ocean, in contrast to the eastern Pacific Ocean (3.5-14.9%) and eastern Bering Sea (4.2-8.7%) (Table 11).

Among Areas

Within regions, lesion incidence ranged from 0.9% to 4.7% off eastern Canada (S. Gulf of St. Lawrence, Scotian Shelf, and Bay of Fundy); 0-100% in eastern Bering Sea; and 0-18.0% off western Canada (Table 11). High-incidence localities were inshore areas off eastern Canada (Morrison et al. 1982); southeast sector of Bering Sea (McCain et al. 1978); and south Queen Charlotte Sound off western Canada (Table 3).

Among Years

No information was provided by other investigations.

Among Seasons

Off eastern Canada, lesion incidence was not correlated with season (Morrison et al. 1982). Off British Columbia, Stich et al. (1976) reported peak incidence (for combined areas) in spring, coinciding with recruitment of the new year-class. The current study, which examined individual areas, revealed a seasonal relationship in only one area (3C) of the seven involved (Table 4).

Among Length Intervals and/or Age-classes

Results were mixed. Lesion incidence varied inversely with length off eastern Canada (Morrison et al. 1982) and western Canada (Stich et al. 1976; this study), but not in eastern Bering Sea. However, in all three regions, incidence was reported to be zero, or nearly so, for age-1 cod, or at least very small cod (< = 29 cm FL) (Levings 1968; Stich et al. 1976; Morrison et al. 1982). The exception was the research vessel samples from the current study (Table 2). However, in the latter case, the sample (N = 1,436) from Areas 5C+5D (comparable to that of Levings 1968) contained no lesioned cod less than 31 cm FL (N = 202). In contrast, the Area 3C sample (N = 908) contained 40 lesioned cod less than 31 cm FL (N = 109).

Among Sexes

Again results were mixed. Lesion incidence was reported to be higher in females off eastern Canada (Morrison et al. 1982) and western Canada, in 1968 (Levings 1968). However, no difference in lesion incidence among sexes was reported for eastern Bering Sea (McCain et al. 1979) or western Canada during 1973-85, except perhaps off southwest Vancouver Island (Table 3).

Abundance

No other reports dealt with lesion incidence versus abundance.

LESION EFFECTS

Maturity

For cod from eastern Canada, Morrison et al. (1982) reported retarded gonad development of lesioned cod held in captivity. For western Canada, Levings (1968) noted that few mature cod were "tumored", but 79.1% of the immature cod were "tumored". His sample comprised 185 females (45-70 cm FL) collected on February 13, 1968, in Hecate Strait. Results of the present study were similar to those of Levings (Table 8).

Growth

For cod from the eastern Bering Sea, McCain et al. (1979) reported the age-length relationships (based on scales) were similar for "tumored" and "non-tumored" cod. The opposite result was reported for western Canada. Stich et al. (1976) reported "average lengths of tumor-bearing fish at each age to be slightly smaller than those without tumors" (op. cit. p. 2000). Basis for the statement was the age-length relationships (based on scales) of two samples of cod from Area 5A, collected during 1972. Similar results were obtained in the present study, based on cod samples collected from Areas 5A (high lesion incidence) and 5B (low lesion incidence) (Table 9).

Mortality

For cod off eastern Canada, Morrison et al. (1982) noted that lesioned cod held in captivity suffered a high mortality due to bacterial infection. Stich et al. (1976) speculated that tumors might be a factor in the natural mortality of juvenile cod (<49 cm FL), as did Morrison et al. (op. cit.). The present study yielded substantially higher estimates of Z for cod from Area 5A (high lesion incidence) than for cod from Area 5B (low incidence) (Table 10).

DISCUSSION

The current study of lesion incidence and lesion effects has provided important new information, and corroborated results of other studies, with respect to stock delineation, maturation, growth, and mortality rate of Pacific cod off western Canada. Delayed maturation, inhibited growth, and enhanced mortality rate were demonstrated in the current study, but are probably not important except in areas of relatively high lesion incidence, such as Areas 3C and 5A, where important stocks exist. The question of lesion-incidence effect on fecundity remains unanswered. No other study addressed either the maturity or fecundity problems. Differential growth results in the current study (comparing age-length relationships between Areas 5A and 5B) corroborate those of Stich et al. (1976), who compared lengths-at-age of cod, with and without lesions, from Area 5A.

Differential lesion incidence among areas corroborated results of earlier studies based on lesion incidence (Stich et al. 1976) and tagging (Westrheim 1984, 1985). Those indicated little inter-area mingling of cod. Even the exception to the "rule" was accounted for. That is, lesion incidence data provided corroboration for the hypothesis advanced to explain the anomalous cod fishery in MSA 19 (Area 4B) (Westrheim and Pedersen 1986). Perhaps the most important discovery with respect to stock delineation, was the substantial difference between cod inhabiting Areas 5A and 5B--sharply contrasting lesion incidence and mortality rate, as well as differential length-at-age. Heretofore, the cod in these two areas have been treated as a single stock for assessment purposes (Westrheim and Foucher 1985), primarily because no tagging experiments had been undertaken in the region. The earlier results of Stich et al. (1976) had been overlooked.

Since X-cell lesions are now considered to be caused by a protozoan parasite, the variable incidence among areas begs of speculation, if not explanation. Stich et al. (1976) reported, without documentation, that their results "show the highest prevalence in the fish populations inhabiting areas close to major sea-lion colonies" (op. cit. p. 2000). A recent report of Bigg (1985) updates the information on distribution and abundance of sea-lions along the coast of British Columbia. The principal rookery for Steller sea-lions (Eumetopias jubivatus) is located in the Scott Islands, immediately

westward of Cook Bank (Area 5A). Furthermore, year-round and wintering sites are numerous along the west coast of Vancouver Island (Areas 3C and 3D), for both the Steller sea-lion and the less numerous California sea-lion (Zalophus californianus). In Canadian waters northward of the Scott Islands, concentrations of sea lions are less numerous, and no important sites are located near grounds occupied by Pacific cod. However, cause and effect have not been established, nor was it within the scope of this study to do so.

SUMMARY

The current study has chronicled the varied nomenclature of parabranchial X-cell lesions in Atlantic and Pacific cod; investigated lesion incidence among 238,699 trawl-caught Pacific cod from British Columbia waters during 1968-85 with respect to sampling method, length interval, sex, area, season, year, and cod abundance; investigated effects of lesions on maturation, growth, and mortality rate; and reviewed the results of other investigations in British Columbia and elsewhere.

Parabranchial X-cell lesions were first reported, in 1929, as adenomas in Atlantic cod, and adenocarcinomas in Pacific cod. Subsequent "names" have been carcinoids, chemodectoma-like tumors, tumors, and finally, in 1981, parabranchial X-cell lesions, caused by an as yet unidentified protozoan parasite.

Results of lesion-incidence investigations were as follows:

1. Sampling method. Incidence ranged from 2.4 to 8.1%, in part due to differential seasonal sampling, and possibly differential criteria applied at sea and at dockside.

2. Length interval. Incidence varied inversely with length interval, regardless of sampling method, area, season, or year.

3. Sex. Incidence was significantly higher in males in SPD samples as a whole; in Area 3C; and in immature cod. In all other tests, incidence was not significantly different among sexes.

4. Area. Lesion incidence ranged from 0.7 to 11.0% in STD samples. High-incidence areas were 3C (5.2%), 3D (8.4%), and 5A (11.0%). In the remaining areas (4B, 5B, 5C, 5D), incidence was 0.7-3.5%.

5. Season. Overall lesion incidence was maximal during April-June (4.7%), and declined thereafter to a minimum of 2.3% during January-March. However, there was no consistent pattern among areas.

6. Year. Lesion incidence was generally above average during 1972-77, and below average thereafter, except for Area 4B, which exhibited the opposite pattern. The anomalous pattern for Area 4B was attributed to the anomalous immigration of Area 3C cod into the southern portion of Area 4B during 1974-85.

7. Cod Abundance. No clear-cut relationship was evident between lesion incidence and cod abundance. However, lesion incidence has generally declined in all areas since about 1978, coincident with a coastwide decline in cod abundance.

Lesion effects delineated were inhibition of maturation and growth, and increased mortality rate.

1. Maturation. Length at 50% maturity of male cod was larger for those afflicted with lesions than those not so afflicted, in Areas 3C (47 vs 44 cm) and 5C+5D (50 vs 47 cm). Inadequate samples precluded a comparison of females in these areas, and of both sexes in other areas.

2. Growth. Mean lengths of age-2 and age-3 cod were consistently larger in Area 5B than in Area 5A during April-June and July-September--1.6-3.7 cm, or 3.2-6.4%, larger. Lesion incidence was sharply contrasted in the two adjacent areas--3.7 (April-June) and 2.3% (July-September) in Area 5B; 10.9 (April-June) and 11.3% (July-September) in Area 5A.

3. Mortality rate. Estimated instantaneous total mortality rate (Z) during April-September 1968-84 was 1.33-1.47 for cod from Area 5A (with a high lesion incidence), compared to 0.98-1.07 for cod from Area 5B (with a low lesion incidence)--Z was 36-37% higher in Area 5A.

Results of other investigations were not always similar to those of the current study.

Geographically, lesion incidence was relatively low in the eastern (2.0%) and western (2.1%) Atlantic Ocean, compared to the eastern Pacific Ocean (3.5-~14.9%) and Bering Sea (4.2-8.7%). Within regions, incidence was generally higher inshore than offshore in the western Atlantic Ocean, but not so in the eastern Pacific and Bering Sea.

Temporally, overall incidence was maximal in spring for the 1968-73 and 1968-85 studies of British Columbia cod. No seasonal pattern was exhibited by cod sampled from the western Atlantic Ocean, nor for B.C. cod within all but one area.

Among length intervals, results were mixed, even among studies in British Columbia. Inverse relationship of lesion incidence to length interval was reported for the western Atlantic Ocean, and the 1968-73 and 1968-85 studies in B.C. waters. No relationship with length was reported for the eastern Bering Sea, or the 1968 study in B.C. waters.

Among sexes, results were also mixed. Higher incidence was reported for female cod than male cod in the western Atlantic Ocean, and in B.C. waters, in the 1968 study only.

No other investigations dealt with inter-year variations in lesion abundance, nor with cod abundance.

Lesion-effects studies by other investigations were limited to maturity and growth.

With respect to maturity, the 1968 B.C. study noted that few mature cod were "tumored", but most of the immature cod were so afflicted.

With respect to growth, the 1968-73 B.C. study reported that tumor-bearing cod sampled from Area 5A were smaller, at each age, than those not so afflicted, from the same area. Comparable studies in the eastern Bering Sea revealed no difference in length-at-age between "tumored" and "untumored" cod.

Source of the parasite which allegedly causes parabranchial lesions may be sea-lions. Stich et al. (1976) noted, without documentation, the direct correlation of "tumor" incidence with sea-lion abundance. The current study documented this correlation. No other investigation dealt with sources.

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Pacific cod length-frequency records with respect to lesion incidence were not included in the groundfish data base at the Pacific Biological Station. Hence, all compilations were completed manually, a tedious task at best. Furthermore, these compilations took place over an extended period of time, primarily due to higher priorities assigned to other important cod studies. The following personnel participated in the onerous task of compilation: C. E. Bibby, S. R. M. Morrison, D. F. Plested, and L. Zado. The author is indeed grateful for their assistance, particularly to C. E. Bibby, who initiated the compilation, and to D. F. Plested, who completed the compilation, and at the last as a "volunteer" worker.

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Table 1. Numbers of Pacific cod sampled for parabranchial lesions, by sampling method, sex, and 3-cm length interval, 1968-85.

Fork length (cm)	Dockside				Research vessel		
	Standard	Special					
	M&F	M	F	T	M	F	T
17	--	--	--	--	5	6	11
20	--	--	--	--	19	15	34
23	--	--	5	7	31	27	58
26	6	14	17	31	41	41	82
29	23	21	17	38	51	55	106
32	59	11	10	21	54	52	106
35	231	30	30	60	63	54	117
38	1435	151	124	275	58	68	126
41	4807	486	432	918	62	70	132
44	11945	1094	1019	2113	67	71	138
47	20045	1672	1397	3069	66	67	133
50	26632	2282	1772	4054	70	71	141
53	29024	3066	2172	5238	73	81	154
56	30187	3538	2569	6107	72	79	151
59	29210	3382	2922	6304	70	84	154
62	25970	2839	2744	5583	70	71	141
65	20610	2146	2379	4525	63	69	132
68	14661	1241	1675	2916	51	52	103
71	9841	736	1200	1936	37	73	110
74	5864	309	754	1063	31	72	103
77	3142	149	416	565	14	42	56
80	1563	66	239	305	4	32	36
83	698	16	93	109	1	6	7
86	286	5	43	48	1	9	10
89	84	1	8	9	0	1	1
92	26	--	3	3	0	1	1
95	5	--	1	1	1	--	1
98	2	--	--	1	--	--	--
Total	236355	23257	22042	45299	1075	1269	2344

Table 2. Incidence (%) of parabranchial lesions in Pacific cod, by sampling method, sex, and 3-cm length interval, 1968-85.

Fork length (cm)	Dockside[a]				Research vessel[b]		
	Standard	Special					
	M&F	M	F	T	M	F	T
17	--	--	--	--	(0)	(0)	(9.1)
20	--	--	--	--	(0)	(0)	(0)
23	--	(0)	(0)	(0)	(12.9)	(14.8)	13.8
26	(0)	(0)	(0)	(0)	(17.1)	(26.8)	22.0
29	(4.3)	(0)	(0)	(0)	5.9	14.5	10.4
32	(1.7)	(9.1)	(0)	(4.8)	9.3	9.6	9.4
35	2.6	(6.7)	(3.3)	(5.0)	11.1	5.6	8.5
38	3.6	2.0	8.1	4.7	13.8	14.7	14.3
41	6.5	6.4	4.4	5.4	12.9	14.3	13.6
44	6.1	4.9	4.0	4.5	20.9	14.1	17.4
47	5.7	4.7	5.1	4.9	9.1	19.4	14.3
50	4.9	4.5	3.1	3.9	8.6	21.1	14.9
53	4.4	3.9	2.5	3.4	6.8	9.9	8.4
56	3.7	2.9	1.9	2.5	6.9	3.8	5.3
59	2.9	1.9	1.5	1.7	1.4	2.4	1.9
62	2.5	2.0	1.6	1.8	1.4	4.2	2.8
65	1.9	1.3	0.8	1.1	0	1.4	0.8
68	1.5	0.7	1.1	0.9	0	0	0
71	1.1	0.5	0.4	0.5	0	1.4	0.9
74	1.0	0	0.7	0.5	0	1.4	1.0
77	0.5	0	0.5	0.4	0	(2.4)	1.8
80	0.8	0	0.4	0.3	0	(3.1)	(2.8)
83	0.4	(0)	(0)	0	0	0	(0)
86	0.3	(0)	(0)	(0)	0	(11.1)	(10.0)
89	(1.2)	(0)	(0)	(0)	--	0	(0)
92	(0)	--	(0)	(0)	--	0	(0)
95	(0)	--	(0)	(0)	(0)	--	(0)
98	(0)	--	(0)	(0)	--	--	--
Total	3.5	2.8	2.0	2.4	7.4	8.7	8.1

[a]Values in parentheses based on <100 specimens.
[b]Values in parentheses based on < 50 specimens.

Table 3. Incidence (%) of parabranchial lesions in Pacific cod, by sampling method, sex, and 3-cm length interval, 1968-85. (N = numbers sampled.)

Area		Dockside				Research Vessel		
		Standard	Special					
		M&F	M	F	T	M	F	T
4B	%	0.7	2.2	1.7	1.9	--	--	--
	(N)	(43976)	(4377)	(4507)	(8884)			
3C	%	5.2	5.0	2.9	4.1	17.8	18.3	18.1
	(N)	(72946)	(6459)	(4932)	(11391)	(338)	(520)	(908)
3D	%	8.4	--	--	--	--	--	--
	(N)	(6178)						
5A	%	11.0	13.2	10.6	11.8	--	--	--
	(N)	(15760)	(652)	(761)	(1413)			
5B	%	3.0	3.5	3.5	3.6	--	--	--
	(N)	(7880)	(595)	(664)	(1259)			
5C	%	1.5	1.2	1.1	1.1			
	(N)	(33673)	(3033)	(3080)	(6113)			
5D	%	1.9	1.2	1.0	1.1			
	(N)	(55942)	(8141)	(8098)	(16239)			
5C+5D		----------			%	1.6	2.0	1.8
					(N)	(687)	(749)	(1436)
T	%	3.5	2.8	2.0	2.4	7.4	8.7	8.1
	(N)	(236355)	(23257)	(22042)	(45300)	(1075)	(1269)	(2344)

Table 4. Incidence (%) of parabranchial lesions in standard dockside samples of Pacific cod, by quarter-year and major area, 1968-1985. (N = numbers sampled; Land. = cumulative tonnes landed.)

Area	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
4B %	0.6	0.4	1.6	1.0
(N)	(22147)	(5054)	(3960)	(12815)
(Land.)	(6272)	(1923)	(2176)	(5258)
3C %	3.5	6.9	5.1	5.7
(N)	(3973)	(23734)	(17344)	(8075)
(Land.)	(16156)	(12259)	(5171)	(1860)
3D %	9.4	10.0	5.7	--
(N)	(652)	(3272)	(2254)	(--)
(Land.)	(397)	(1182)	(522)	(270)
5A %	13.7	10.9	11.3	7.3
(N)	(284)	(10876)	(4474)	(316)
(Land.)	(442)	(5243)	(3364)	(978)
5B %	3.4	3.7	2.3	4.2
(N)	(493)	(3618)	(3649)	(120)
(Land.)	(329)	(6136)	(5383)	(1077)
5C %	1.2	1.5	1.5	3.5
(N)	(6806)	(19229)	(6396)	(1242)
(Land.)	(4886)	(8657)	(3975)	(583)
5D %	2.3	2.2	1.1	2.2
(N)	(14917)	(17959)	(14367)	(8699)
(Land.)	(9257)	(12836)	(14521)	(3337)
T %	2.2	4.7	3.7	2.7
(N)	(69092)	(83552)	(52444)	(31267)
(Land.)	(37839)	(48236)	(35112)	(13363)

Table 5. Unweighted mean incidence (%) of parabranchial lesions, by quarter-year and important MSA, in standard dockside samples of Pacific cod from Area 4B, 1968-85. (N = numbers sampled; Land. = cumulative tonnes landed.)

MSA		Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	TOTAL
14	%	0.1	0	0	0	0.1
	(N)	(4253)	(1813)	(164)	(1783)	(8013)
	(Land.)	(537)	(227)	(63)	(461)	(1288)
17	%	0.1	0	--	0	0.1
	(N)	(9007)	(286)	(0)	(1280)	(10572)
	(Land.)	(1348)	(129)	(11)	(219)	(1707)
18	%	0.5	0.5	--	0	0.5
	(N)	(5836)	(1740)	(0)	(580)	(8156)
	(Land.)	(2288)	(714)	(190)	(803)	(3995)
19	%	2.3	0.8	2.1	1.7	1.7
	(N)	(1029)	(457)	(3485)	(6083)	(11054)
	(Land.)	(1199)	(319)	(1523)	(3253)	(6344)

Table 6. Incidence (%) of parabranchial lesions, by year, in standard dockside samples of Pacific cod from important MSAs in Area 4B, and Areas 3C and 3D, 1968-85.

	4B					
Year	14	17	18	19	3C	3D
1968	--	--	--	--	3.0	7.3
1969	0	0	0.2	--	2.9	7.7
1970	0	0	0	0.2	4.5	10.0
1971	0	0	T	--	3.1	6.3
1972	0	0	--	--	5.9	12.3
1973	0	0	0	--	6.2	14.6
1974	0	0.1	0.2	1.0	7.7	--
1975	0	0	0	1.8	6.3	--
1976	0	0	0.4	2.7	4.9	5.4
1977	0	0	1.1	2.7	5.1	--
1978	0.2	0.3	1.8	3.3	8.3	--
1979	0	0.3	0.9	2.3	11.8	--
1980	0	--	--	0.7	8.7	17.0
1981	--	--	--	1.8	3.9	--
1982	1.0	--	--	1.3	3.3	12.8
1983	--	--	--	1.2	3.7	--
1984	--	--	--	1.0	0.7	0
1985	--	--	--	--	6.7	--
Unweighted mean	0.1	0.1	0.5	1.7	5.4	9.3

Table 7. Maturity (%), by lesion presence (No, Yes), sex, and 3-cm length interval, of Pacific cod collected in special dockside samples from Areas 4B, 3C, and 5C+5D during January-March 1973-85. (Values in parentheses based on N < 10; N = numbers sampled.)

Fork length	4B				3C				5C+5D			
	Male		Female		Male		Female		Male		Female	
(cm)	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
23-29	--	--	--	--	--	--	--	--	(0)	--	0	--
32	--	--	--	--	--	--	--	--	(33)	--	--	--
35	0	--	(0)	--	--	(0)	(0)	(0)	(25)	--	14	--
38	11	--	0	--	(75)	(0)	(0)	(0)	(26)	--	20	--
41	21	(100)	4	(0)	38	(33)	19	(0)	19	(0)	84	--
44	41	(50)	23	(0)	56	15	21	(0)	40	(0)	20	(0)
47	65	(75)	48	0	73	50	33	0	59	(50)	36	(13)
50	83	(67)	71	33	95	70	74	0	70	30	58	(0)
53	93	89	83	(0)	99	94	97	(0)	85	71	72	(25)
56	98	100	90	50	100	95	99	(0)	91	80	81	(17)
59	98	(83)	96	(67)	100	85	100	(75)	94	67	93	(0)
62	99	90	97	(80)	100	96	100	(25)	99	100	98	(0)
65	100	(100)	97	(100)	100	100	100	(67)	100	100	99	(0)
>65	100	(100)	92-100	(50)	100	100	100	(99)	100	--	100	(100)
N	2,428	62	2,513	38	5,025	213	3,745	71	4,270	46	4,265	43

Table 8. Incidence (%) of parabranchial lesions, by sex and 3-cm length interval, in special dockside samples of immature (I) and mature (M) Pacific cod from Areas 4B, 3C, and 5C+5D during January-March 1973-85. (N = numbers sampled.)

Male length (cm)	4B				3C				5C+5D			
	Male		Female		Male		Female		Male		Female	
	I[a]	M[b]	I[a]	M[b]	I[a]	M[b]	I[a]	M[b]	I[a]	M[b]	I[a]	M[b]
23-32	--	--	--	--	--	--	--	--	(0)	--	(0)	--
32	--	--	--	--	--	--	--	--	(0)	(0)	--	--
35	(0)	--	(0)	--	(100)	--	(50.0)	--	(0)	(0)	(0)	(0)
38	0	(0)	0	--	(33.3)	(0)	(37.5)	--	0	(0)	0	(0)
41	0	5.3	6.7	(0)	20.0	16.7	18.8	(0)	1.3	(0)	0	(0)
44	2.0	2.8	0	0	30.6	5.9	20.5	(0)	1.2	0	1.8	0
47	1.3	2.1	5.6	0	24.5	10.8	14.7	0	1.5	1.0	3.8	1.0
50	5.1	2.1	3.2	0.7	37.0	7.0	24.4	0	4.7	0.9	5.4	0
53	6.7	4.3	10.0	0	(25.0)	4.3	52.9	0	2.4	1.0	2.5	0.3
56	0	2.3	11.8	1.4	(66.7)	4.4	(44.4)	0	3.6	1.4	5.2	0.2
59	(16.7)	1.6	7.1	0.7	(80.0)	2.6	(50.0)	0.6	2.9	0.4	8.7	0
62	(33.3)	3.4	9.1	1.4	(100)	2.9	(85.7)	0.4	(0)	1.1	2.2	0
65	--	1.8	(0)	0.9	--	1.2	(100)	0.4	(0)	1.0	(25.0)	0
>65	--	0.5	--	0.2	0.5	0.5	(100)	0.3	--	0	(100)	0.3
Total	2.5	2.5	4.8	0.7	31.2	3.2	27.3	0.3	2.3	0.8	4.1	0.2
N	356	2134	499	2052	157	5081	220	3596	733	3583	897	3411

[a]Values in parentheses based on N < 10.
[b]Values in parentheses based on N < 20.

Table 9. Mean lengths (cm), by year-class, of age-2 and age-3 Pacific cod landed from Areas 5A and 5B during April-June and July-September 1968-80.

Year class	Age 2		Age 3	
	5A	5B	5A	5B
		April-June		
1966	51.5	52.2	56.6	63.0
1970	48.7	51.9	61.0	58.4
1974	49.7	48.8	58.1	59.1
1975	48.3	48.9	57.5	59.4
1976	50.0	51.7	57.3	62.2
1977	50.5	54.8	55.9	62.2
Mean	49.8	51.4	57.7	60.7
		July-September		
1966	52.4	54.0	59.0	61.7
1974	49.6	50.0	57.3	59.4
1975	48.7	52.0	56.7	60.6
1976	48.0	52.3	58.4	64.5
Mean	49.7	52.1	57.9	61.6

Table 10. Computations of Z, by age-classes and year-classes, for Pacific cod landed from Areas 5A and 5B during April-September 1968-84.

Age (y)	Age-classes[a]		Year-classes[b]	
	5A	5B	5A	5B
		Numbers per hour		
2	58.9	27.1	66.7	28.7
3	39.0	18.7	57.9	22.2
4	9.6	10.2	10.9	11.2
5	2.7	2.7	2.5	2.8
6	0.7	1.1	0.7	0.2
		Regression of ln N/h on age (ages 3-6)		
Parameters				
a	7.64	6.01	8.38	6.45
b	-1.33	-0.98	-1.47	-1.07
r	-0.999+	-0.991	-0.998	-0.993

[a]During 1968-84
[b]1966-78

Table 11. Incidence (%) of parabranchial lesions in Pacific cod, by region and investigation, 1968-85.

Region	Time	Sample[a] type	Incidence (%) Mean	Incidence (%) Range	N	Investigation
East Pacific (W. Canada)	Feb 1968	RV	~14.9	NR [b]	2,013	Levings (1968)
	1968-1973	L	NR	0-11.4	108,336	Stich et al. (1976)
	1968-1985	L	3.5	0.7-11.0	236,355	This study.
	Apr-Feb 1975-76	RV	8.3	1.8-18.0	2,344	This study.
East Bering Sea	Sep. 1975	RV	4.2	NR	2,096	Alpers et al. (1977)
	Sep-Oct 1975	RV	7.4	NR	NR	McCain et al. (1978)
	Sep-Oct 1975	RV	7.4	0-100	NR	Wellings et al. (1977)
	Mar-Jun 1976	RV	8.7	1.1-7.3	4,654	McCain et al. (1979)
West Atlantic (S. Gulf of St. Lawrence, Scotian Shelf, and Passamaquoddy Bay).	1974-76	NR	2.0	0.9-4.7	4,256	Morrison et al. (1982)
East Atlantic (North Sea)	NR	NR	2.1	NR	NR	Watermann & Dethlefsen (1980)[c]

aL = commercial landings; RV = research vessel.
bNR = not reported.
cCited by Morrison et al. (1982).

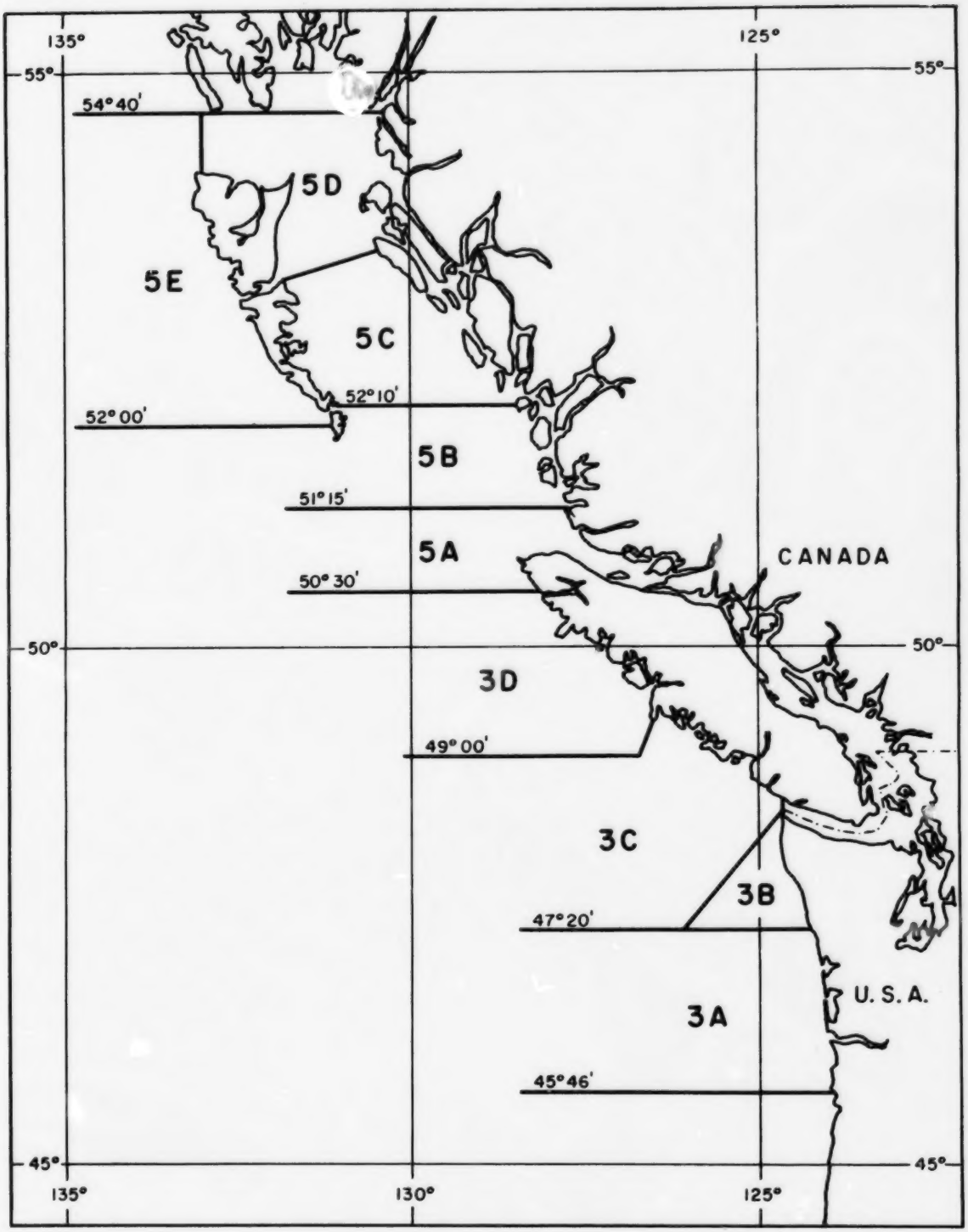


Fig. 1. Major statistical areas for groundfish off British Columbia.

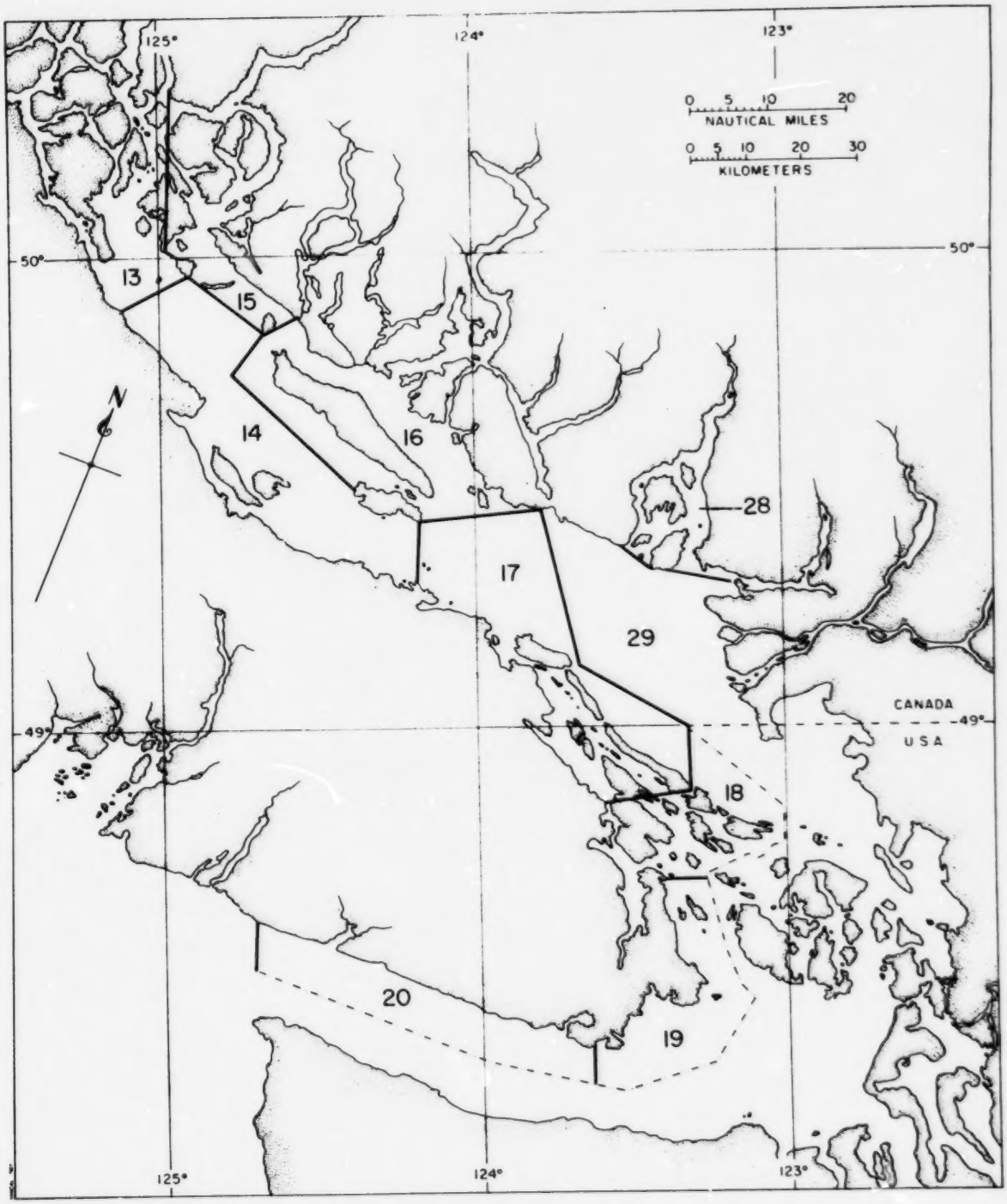


Fig. 2. Minor statistical areas for groundfish in Area 4B.

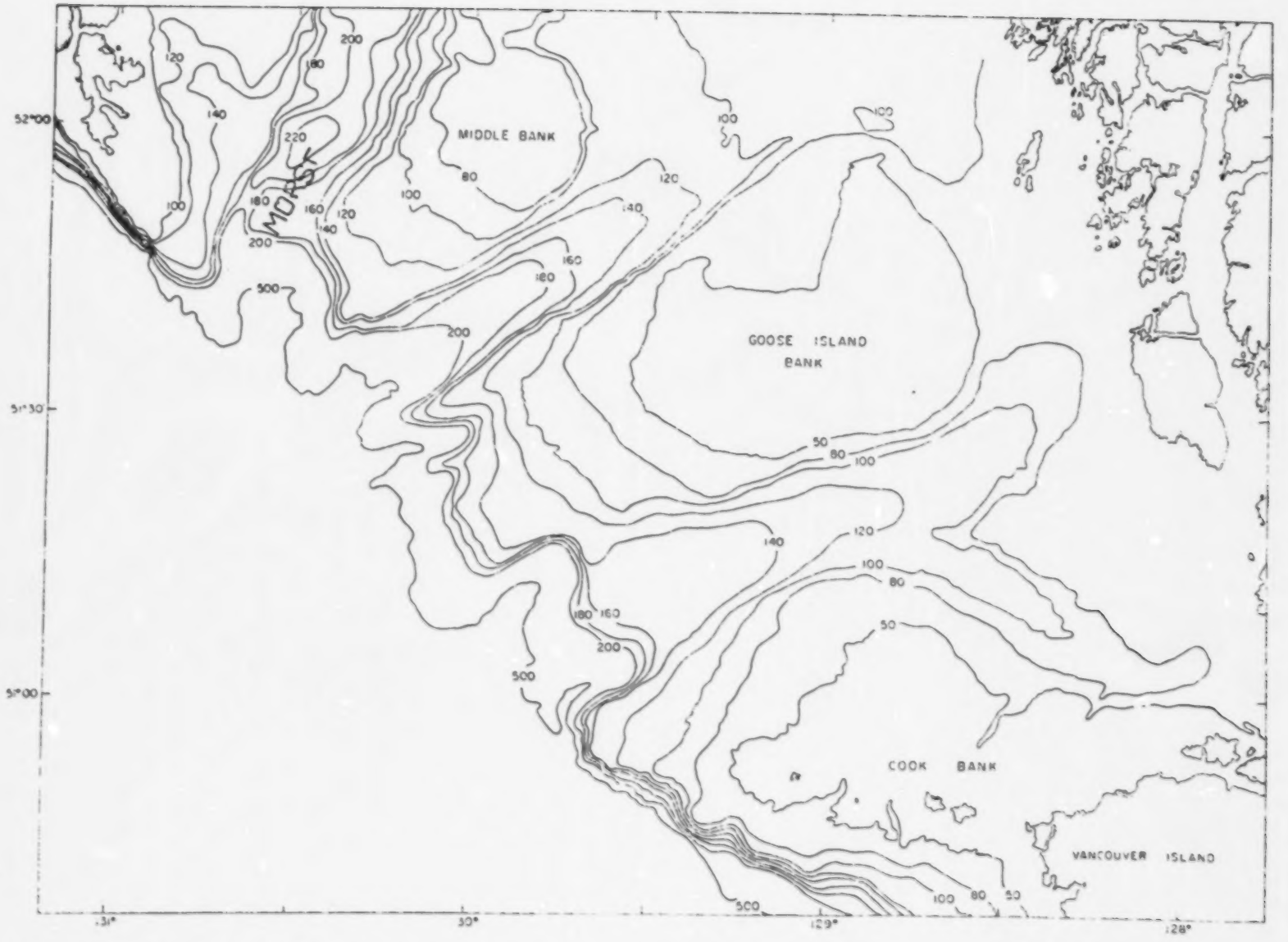


Fig. 3. Bathymetric chart of Queen Charlotte Sound (Areas 5A and 5B).

Fig. 4. Length-frequencies (%) of Pacific cod in standard dockside samples collected during 1968-85: total versus lesions.

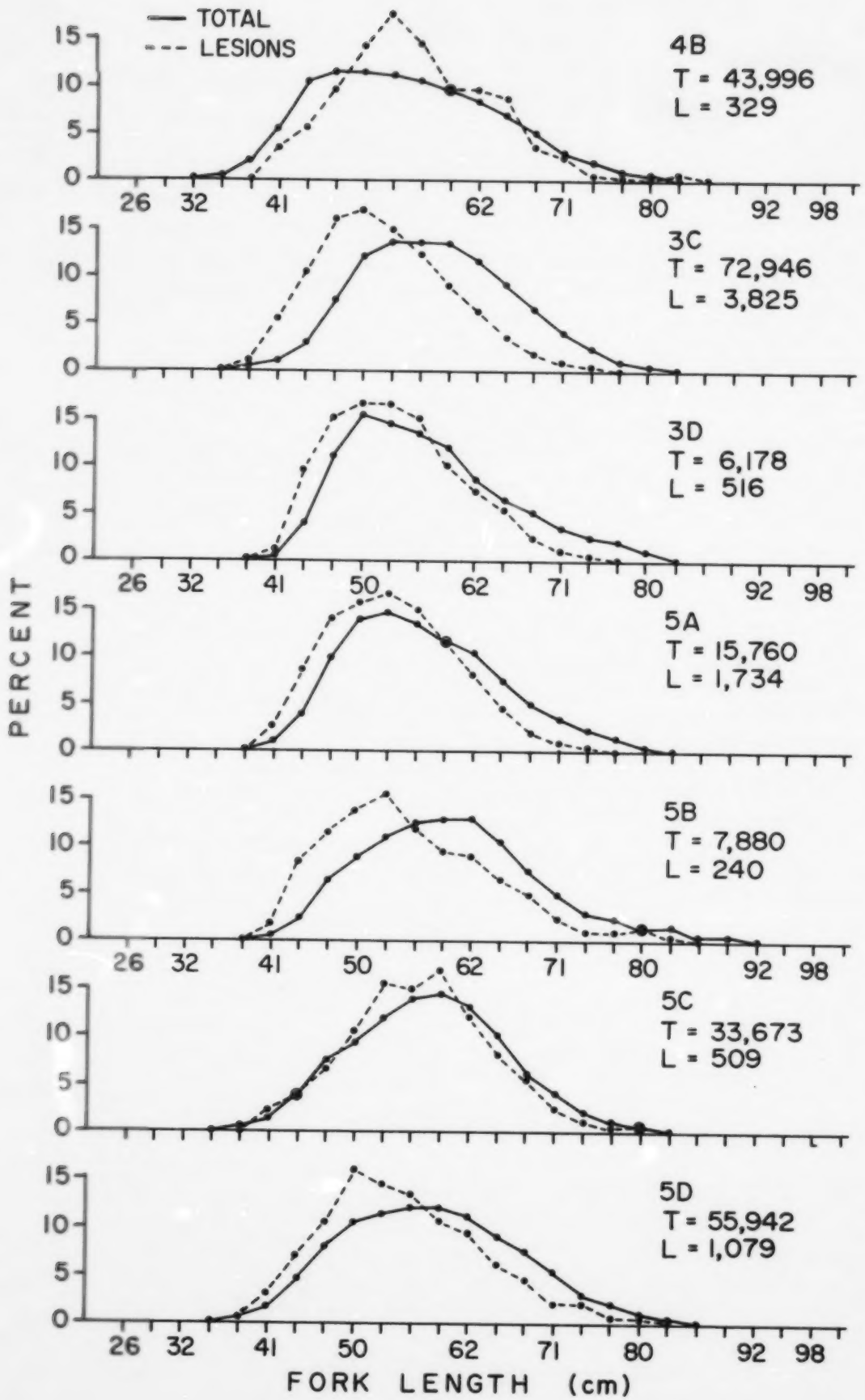

TOTAL
LESIONS
4B
T = 43,996
L = 329
3C
T = 72,946
L = 3,825
3D
T = 6,178
L = 516
5A
T = 15,760
L = 1,734
5B
T = 7,880
L = 240
5C
T = 33,673
L = 509
5D
T = 55,942
L = 1,079
PERCENT
FORK LENGTH (cm)
0
5
10
15
26
32
41
50
62
71
80
92
98

Fig. 5. Lesion-incidence anomalies: deviations of annual incidence (%) from overall, unweighted mean incidence (%), by area, in standard dockside samples, 1968-85. (U = unknown; no data).

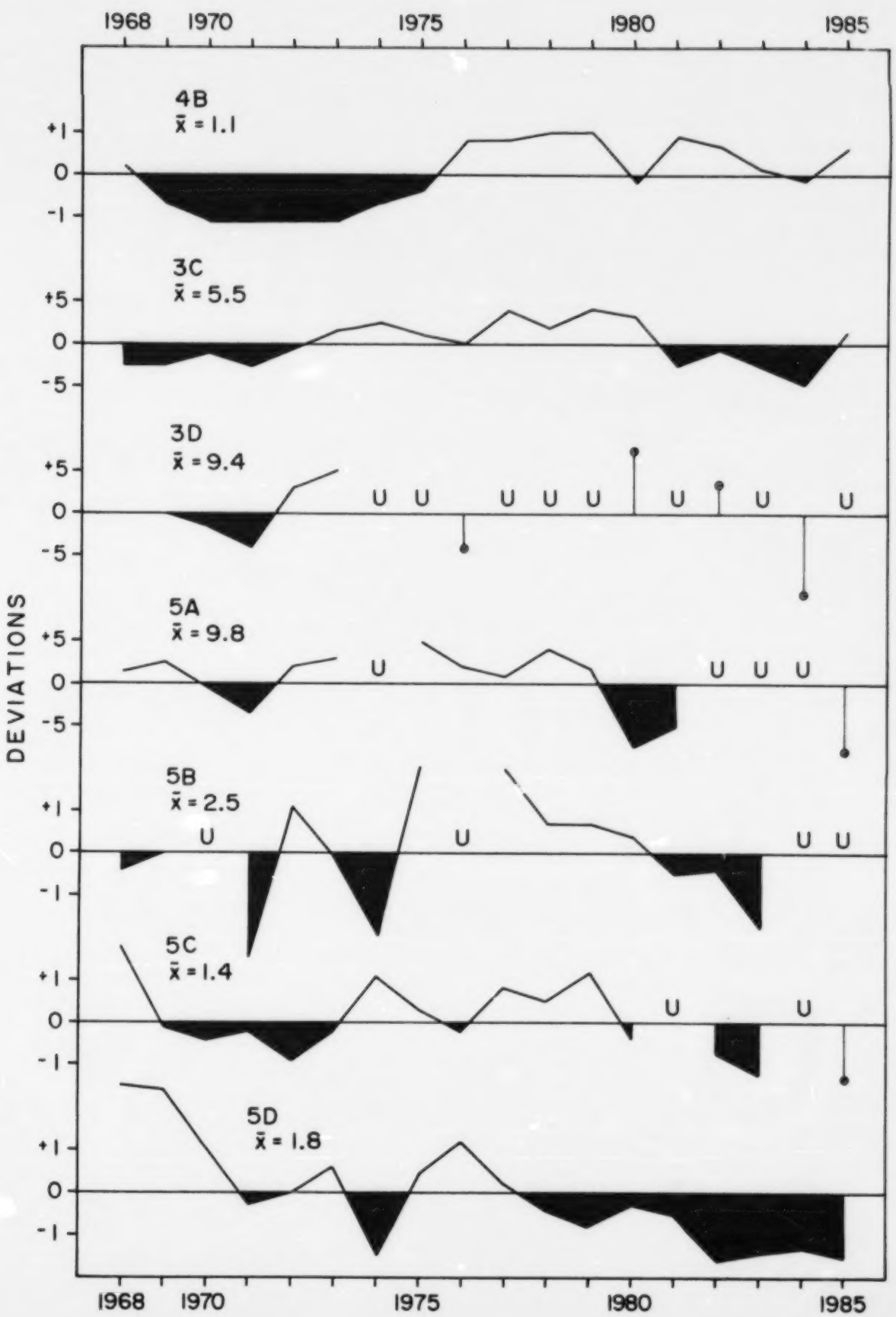
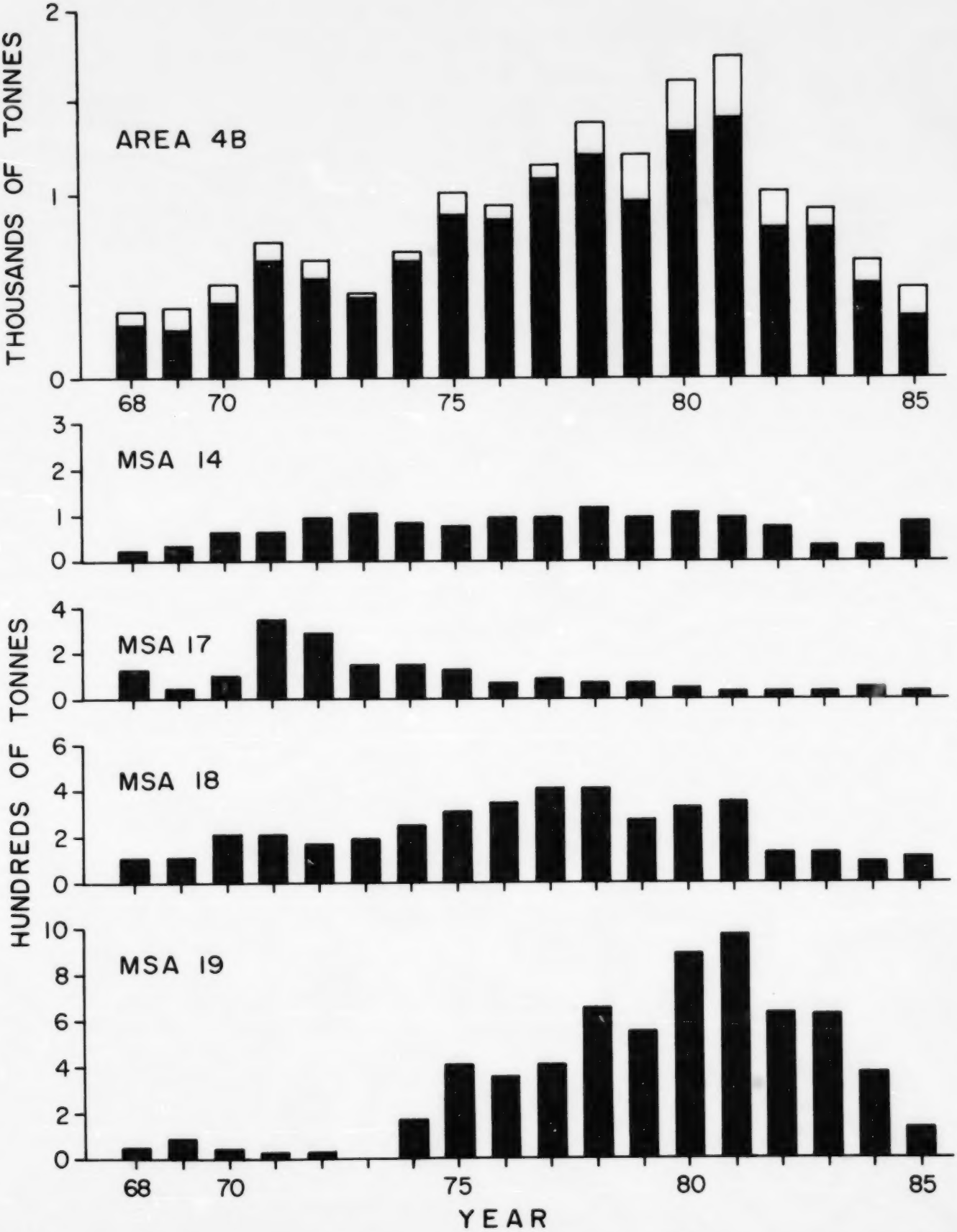

1968
1970
1975
1980
1985
4B
x̄ = 1.1
+1
0
-1
3C
x̄ = 5.5
+5
0
-5
3D
x̄ = 9.4
+5
0
-5
U
5A
x̄ = 9.8
+5
0
-5
U
5B
x̄ = 2.5
+1
0
-1
U
5C
x̄ = 1.4
+1
0
-1
U
5D
x̄ = 1.8
+1
0
-1
DEVIATIONS

Fig. 6. Annual landings (t) of Pacific cod from Area 4B, and important MSA's, 1968-85.


THOUSANDS OF TONNES
AREA 4B
2
1
0
68
70
75
80
85
MSA 14
3
2
1
0
HUNDREDS OF TONNES
MSA 17
4
2
0
MSA 18
6
4
2
0
MSA 19
10
8
6
4
2
0
68
70
75
80
85
YEAR

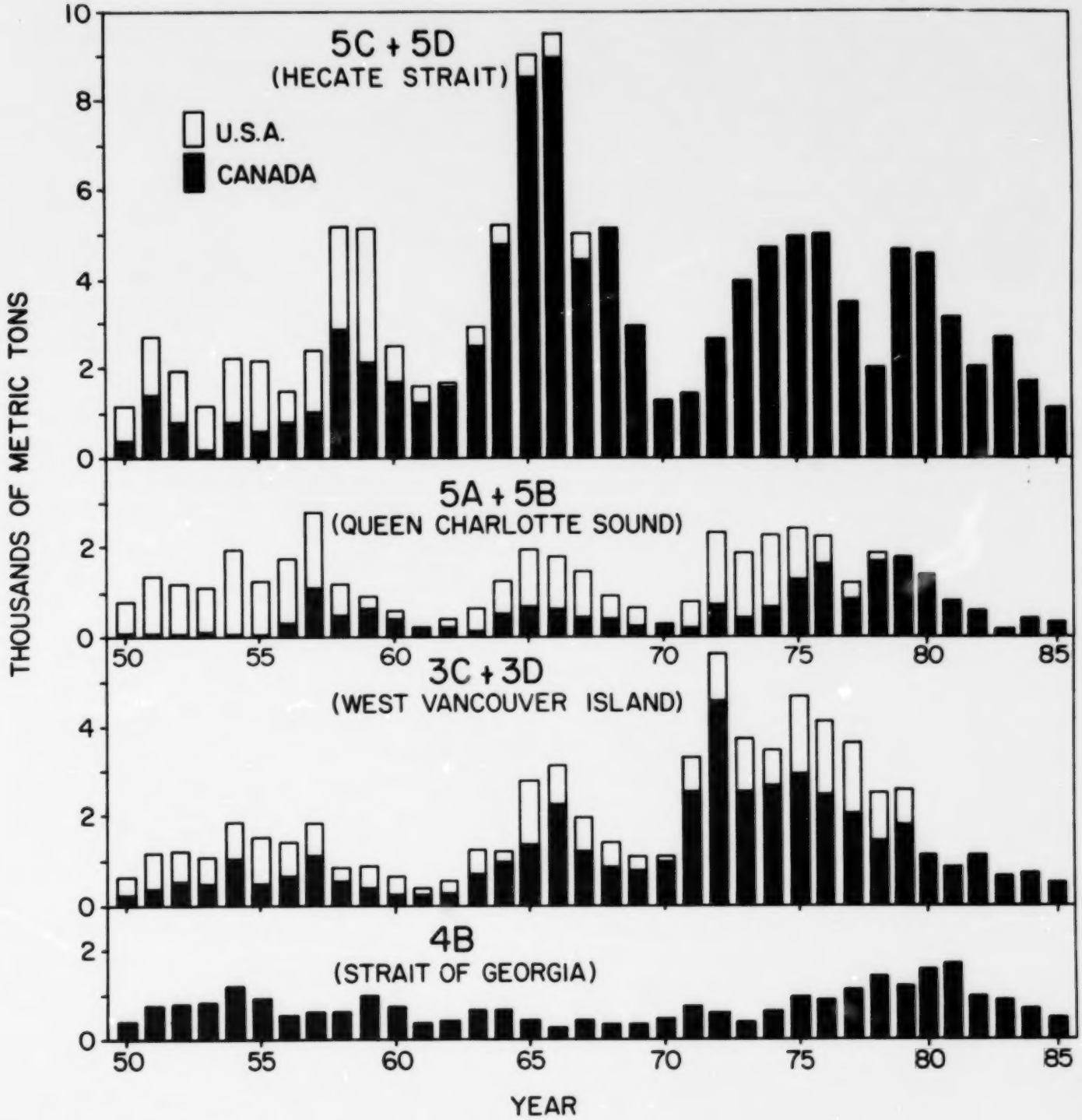


Fig. 7. Canada-U.S. landings (t) of Pacific cod, by region, 1956-85.

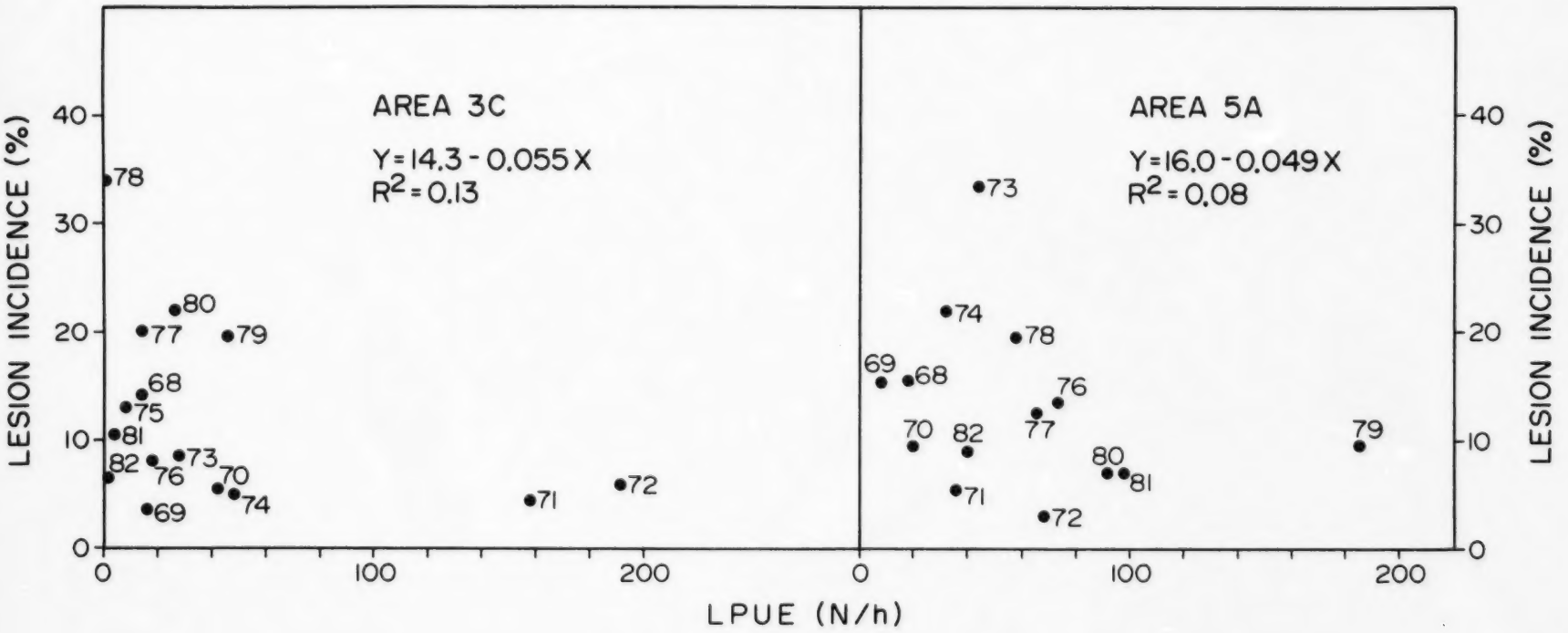


Fig. 8. Lesion incidence (%) versus LPUE (N/h) for age-2 Pacific cod in Areas 3C (Big Bank) and 5A, April-June 1968-82. (No age frequency data available for Area 5A in 1975.)